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INTELLIGENT ROBOTIC SYSTEMS FOR
SPACE EXPLORATION (Rensselaer
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NASA CENTER FOR
INTELLIGENT ROBOTIC
SYSTEMS FOR SPACE
EXPLORATION

NAGW-1333



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Center for Intelligent
Robotic Systems
for Space Exploration

Rensselaer Polytechnic Institute
Troy, New York 12180-3590

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UTTL: NASA Center for Intelligent Robotic Systems for Space Exploration

CORP: Rensselaer Polytechnic Inst., Troy, NY. CSS: (Center for Intelligent Robotic Systems for Space Exploration.)

SAP: Avail: CASI HC A03/MF A01

CIO: UNITED STATES

MAJS: /*ARTIFICIAL INTELLIGENCE/*AUTONOMY/*ROBOTICS/*SPACE EXPLORATION

MINS: / AERONAUTICAL ENGINEERING/ ELECTRICAL ENGINEERING/ ENGINEERS/ MECHANICAL ENGINEERING/ SCIENTISTS/ SYSTEMS ENGINEERING

ABA: Author (revised)

ABS: NASA's program for the civilian exploration of space is a challenge to scientists and engineers to help maintain and further develop the United States' position of leadership in a focused sphere of space activity. Such an ambitious plan requires the contribution and further development of many scientific and technological fields. One research area essential for the success of these space exploration programs is Intelligent Robotic Systems. These systems represent a class of autonomous and semi-autonomous machines that can perform human-like functions with or without human interaction. They are fundamental for activities too hazardous for humans

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or too distant or complex for remote telemanipulation. To meet this challenge, Rensselaer Polytechnic Institute (RPI) has established an Engineering Research Center for Intelligent Robotic Systems for Space Exploration (CIRSSE). The Center was created with a five year \$5.5 million grant from NASA submitted by a team of the Robotics and Automation Laboratories. The Robotics and Automation Laboratories of RPI are the result of the merger of the Robotics and Automation Laboratory of the Department of Electrical, Computer, and Systems Engineering (ECSE) and the Research Laboratory for Kinematics and Robotic Mechanisms of the Department of Mechanical Engineering, Aeronautical Engineering, and Mechanics (ME,AE,&M), in 1987. This report is an examination of the activities that are centered at CIRSSE.

ENTER:

NASA CENTER FOR
INTELLIGENT ROBOTIC
SYSTEMS FOR SPACE
EXPLORATION

NAGW-1333

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Department of Mechanical Engineering, Aeronautical Engineering,
and Mechanics
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NASA CENTER FOR INTELLIGENT ROBOTIC SYSTEMS FOR SPACE EXPLORATION

MOTIVATION

NASA's program for the civilian exploration of space is a challenge to scientists and engineers to help maintain and further develop the United States' position of leadership in a focused sphere of space activity. Such an ambitious plan requires the contribution and further development of many scientific and technological fields.

One research area essential for the success of these space exploration programs is Intelligent Robotic Systems. These systems represent a class of autonomous and semi-autonomous machines that can perform human-like functions with or without human interaction. They are fundamental for activities too hazardous for humans or too distant or complex for remote telemanipulation. To meet this challenge, Rensselaer Polytechnic Institute (RPI) has established an Engineering Research Center for Intelligent Robotic Systems for Space Exploration (CIRSSE).

The Center was created with a five year \$5.5 million grant from NASA submitted by a team of the Robotics and Automation Laboratories.

The Robotics and Automation Laboratories of RPI are the result of the merger of the Robotics and Automation Laboratory of the Department of Electrical, Computer, and Systems Engineering (ECSE) and the Research Laboratory for Kinematics and Robotic Mechanisms of the Department of Mechanical Engineering, Aeronautical Engineering, and Mechanics (ME,AE,&M), in 1987. They both have been created with a generous endowment of the S. McCormick family.

The Robotics and Automation Laboratory of the ECSE Department was established in 1982, and it was dedicated on October 13, 1984. It was created as a Center for research in the areas of Robotics, Prosthetics, and Advanced Automation. Its purpose is to look into the future of robotic and automation systems and develop the theory and prototypes of intelligent machines capable of executing various complicated tasks with minimum interaction with a human operator. Such intelligent machines have wide-range applications, from unmanned explorations of unknown planets, to work in hazardous environments, e.g., nuclear plants, to aid the disabled and immobilized people, to the factory of the future and automated production lines of highly developed industrial plants. The emphasis is in four areas of basic research: visual and other sensors, control theory, computer software and hardware, and simulations. It relates to and strongly draws on the Department's experience in image processing, artificial intelligence, graphics, computers, and controls.

The Laboratory for Kinematics and Robotic Mechanisms of ME,AE,&M was created in 1981 with the purpose to study applications of theoretical mechanics and motion planning in robotic systems.

There are already more than 20 Ph.D. and 50 M.S. graduates of our laboratories, employed in prominent academic and industrial institutions in this country and abroad.

The two labs were merged and moved to the eighth floor of the newly completed \$65 million George M. Low Center for Industrial Innovation (CII). These eight laboratories occupy 5,000 square feet and form the core of the facilities for the NASA funded Center, and house the following facilities:

- Control Lab for Mechanical Structures (CLaMS) - (CII 8208)
- The Computer Room - (CII 8214)
- The Intelligent Robot Laboratory - (CII 8218)
- The Mechanical Robot Laboratory - (CII 8226)
- The Mobile Robot Laboratory - (CII 8108)
- The Control and Automation Laboratory - (CII 8114)
- The Computer Terminal Room - (CII 8118)
- The Vision and Sensing Laboratory - (CII 8124)

About 50 M.S. and Ph.D. students work in the laboratories and occupy offices at the east side of the same floor of the CII.

The CII is dedicated to cross-disciplinary research. It is primarily occupied by the faculty, staff, students and labs associated with the Center for Manufacturing Productivity and Technology Transfer, the Center for Integrated Electronics, the Interactive Computer Graphics Center, the Rensselaer Design Research Center, CIRSSE, and the new academic Department of Decision Sciences and Engineering Systems. The CII was funded jointly and equally with New York State and represents Rensselaer's commitment to the Center concept.

THE CENTER AND ITS MISSION

The NASA Center provides the focal point for a nationwide Center for Intelligent Robotic Systems for Space Exploration.

The Center has two purposes:

1. To accelerate the development and advancement of the theory of Intelligent Control Systems leading to the principles of machine intelligence and control algorithms for autonomous systems.
2. To develop laboratory demonstrations of intelligent robotic systems.

The demonstrations emphasize the concepts and theory essential to the development of an autonomous system for assembly, and repair in space.

These goals are generic to NASA's missions and to the areas of potential leadership as summarized in Figure 1. The rows of the matrix represent the basic research areas associated with intelligent autonomous systems which also match the current expertise of CIR SSE's research team. The columns correspond to NASA's missions for space exploration and planet colonization. The boxes represent the focused areas of leadership in space that will benefit from Rensselaer's research.

CIR SSE ORGANIZATION

The Center is organized according to Figure 2.

THE EXECUTIVE COUNCIL

The Executive Council is chaired by the Center's Director and composed of the faculty of Principal Investigators of the Center who make major decisions about the Center.

<div> <div>NASA Misslons</div> <div>RPI Research</div> </div>	INTELLIGENT ROBOTS FOR SPACE MAINTENANCE	UNMANNED PROSPECTING	NAVIGATION OF AUTONOMOUS MOBILE SYSTEMS	AUTOMATED CONSTRUCTION OF PLANETARY OUTPOSTS
MATHEMATICAL THEORY OF INTELLIGENT CONTROL	THE SPACE REPAIRER	AUTONOMOUS SCIENTIFIC LABORATORY	AUTONOMOUS NAVIGATOR FOR PLANETARY VEHICLES	AUTONOMOUS CONSTRUCTION MACHINE
MULTISENSOR FUSION	INTEGRATION OF SENSORS	OBJECT AND ENVIRONMENT RECOGNITION	SPACE VEHICLES, MOON EXPLORERS, AND PLANET ROVERS USING SENSORY INFORMATION	AUTONOMOUS CONSTRUCTION OF OUTPOSTS
TASK PLANNING AND INTEGRATION	UNPREDICTED MAINTENANCE EXECUTION	EFFECTIVE SAMPLE CLASSIFICATION		
MULTI-ARM MANIPULATION	DEXTEROUS MANIPULATION	SAMPLE MANIPULATION AND HANDLING	—	DEXTEROUS CONSTRUCTION
ADAPTIVE AND LEARNING CONTROL	LOW LEVEL ADAPTATION AND FEEDBACK	ADAPTATION TO ENVIRONMENTAL CHANGES	UNCERTAIN ENVIRONMENTS	LOW LEVEL ADAPTATION AND FEEDBACK OF MOTION AND SENSING
RELIABILITY AND SAFETY	REDUNDANT VS. RELIABLE OPERATION	RELIABLE AND SAFE OPERATION OF SOPHISTICATED INSTRUMENTS	RELIABLE NAVIGATION OF UNMANNED VEHICLES	RELIABLE AND SAFE CONSTRUCTION IN UNFAMILIAR ENVIRONMENTS
PARALLEL COMPUTATION AND INFORMATION MANAGEMENT	COORDINATION OF MORE THAN ONE ROBOT	DATA PROCESSING AND COMMUNICATION USING NEURO-COMPUTERS	NEURONET COMPUTERS FOR SPACE NAVIGATION	COORDINATION OF MANY ROBOTS
DEMONSTRATION OF AN INTELLIGENT ROBOT SYSTEM	SIMULATION OF MAINTENANCE ON A RANDOMLY MOVING PLATFORM	TESTING OF VISUAL SENSORS	TESTING OF SENSOR INTEGRATION WITH ROBOT MOTION	TESTING OF MULTI-ROBOT COORDINATION

Figure 1. The Leadership Matrix

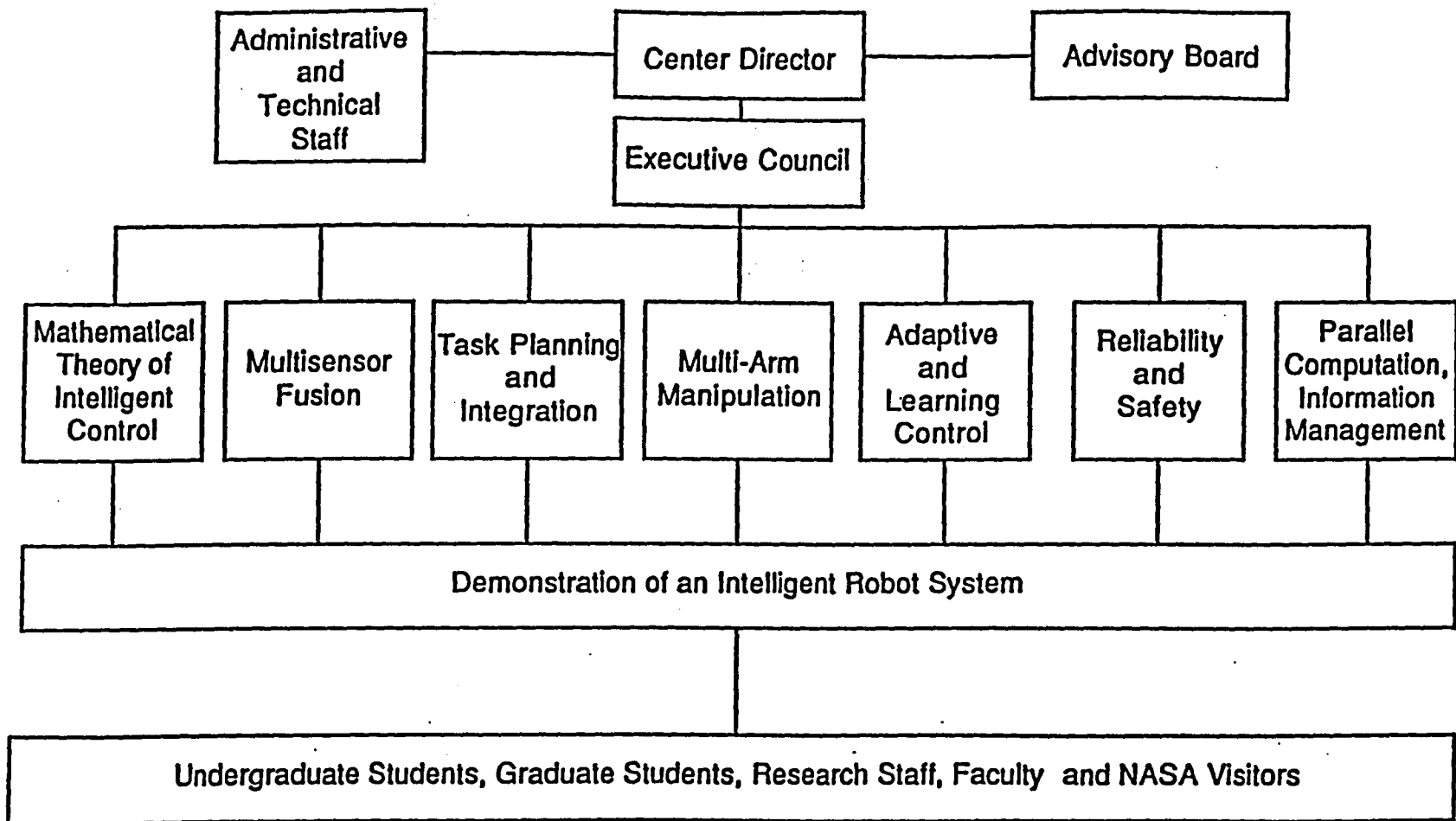


Figure 2. Organization Chart for CIRSSE

GEORGE N. SARIDIS, Professor of ECSE and Director of CIRSSSE; intelligent control systems, pattern recognition, computer systems, robotics, prostheses.

STEPHEN J. DERBY, Associate Professor of ME,AE,&M; mechanisms, kinematics and robotics, computer graphics, design.

ALAN A. DESROCHERS, Professor of ECSE and Associate Director of CIRSSSE; nonlinear systems, robotics, control of automated manufacturing systems.

LESTER A. GERHARDT, Professor of ECSE and Computer Science; communication systems, sensor technology and integration, interactive, computer graphics, digital voice and image processing, adaptive systems, pattern recognition and computer integrated manufacturing.

HOWARD KAUFMAN, Professor of ECSE; digital control systems, adaptive systems applications and theory, optimal control.

ROBERT B. KELLEY, Professor of ECSE; robotic systems, machine intelligence, machine vision, expert systems.

L. KEN LAUDERBAUGH, Assistant Professor of ME,AE,&M; automatic control, manufacturing.

ARTHUR C. SANDERSON, Professor and Chairman of ECSE; robotics, knowledge-based systems, computer vision.

C.N. SHEN, Active Professor Emeritus of ECSE; navigation of mobile robots, laser ranging systems.

JOHN WEN, Assistant Professor of ECSE; multiple-arm manipulation and control, distributed parameter systems.

There are also about 20 Ph.D. and 30 M.S. and undergraduate students working in the Center.

THE ADMINISTRATIVE AND TECHNICAL STAFF

- Betty Lawson, Administrative Assistant
- Denise Elwell, Senior Secretary
- Keith Fieldhouse, Software Engineer
- Ken Walter, Research Engineer

FACILITIES

- Network of Sun Workstations
- Local Ethernet with connection to Rensselaer and outside networks
- GCA P300V and P200V robotic arms
- PUMA 560 and PUMA 600 robot arms
- Custom VME Control System for the PUMA arms
- M.I.T./Scheinman arm
- Prosthetic arm
- Flexible arm testbed
- IBM 7565 robot arms
- Wrist force-torque sensors
- IRI P256 Machine Vision System with Hitachi Camera
- MATROX/TAAC Sun-based Vision System with 2 CCD cameras
- Robotic transporter testbed
- Datacube Based Vision System
- Laser Scanning System

The various machines are presently networked in a hierarchical way. The SUN systems being the mastermind may organize and download programs to the intermediate microcomputers which control the functions of the hardware devices. A software system has been developed which can run and test most of the available control algorithms, as well as recognize, classify, and locate objects. The system is unique because it is interactive and has the potential of integrating the various robotic activities at a high level of sophistication.

FACULTY RESEARCH INTERESTS

The faculty combine many years of experience in the fields of theoretical and applied robotics, industrial process control and automation, advanced manufacturing and machine tooling, intelligent, optimal, adaptive and singular control, process modeling, computer vision and sensing systems, speech and image processing and analysis, artificial intelligence and intelligent machines, as well as, computer simulation, software and special architectures. The main goal of the research pursued by the faculty is the creation and development of intelligent machines operating autonomously and interactively in structured and unstructured, unfamiliar environments.

More specifically, the staff of the laboratories with the financial and technical assistance from the government and industrial sponsors focus their research activities on the following areas of interest:

- Hierarchically Intelligent Control
- Advanced Linguistics for Computer Intelligence
- High Level Languages for Advanced Process Control
- Parallel Processing for Advanced Control Algorithms
- Self-Organizing, Learning, and Adaptive Control Systems
- System Identification and Process Modeling
- State Space Models of Robotic Systems
- Optimal, Suboptimal, Singular and Robust Control Systems
- Distributed Parameter Control Systems
- Distributed Computer Control for Networks of Automatic Processes
- Pattern Recognition for Signal Analysis and Classification
- Robot Navigation and Locomotion
- Robotic Vision Systems, Scene Analysis and Object Tracking
- Force Sensing for Robots
- Interactive Computer Graphics for Simulations and Design
- Robot Simulation
- Automated Process Control
- Material Handling and Advanced Manufacturing
- Machine Tooling
- Voice Recognition

- Computer Vision Systems
- AI and Expert Systems for Robots
- Eye Tracking

CIRSSE has been created to promote basic research in the fast growing area of Robotics and Automation for Space Exploration and to provide the fundamentals for the design of intelligent machines of the future as a service to the scientific and industrial community.

BIOGRAPHIES

Stephen J. Derby received his B.S. in 1976, M.S. in 1977 and Ph.D. in 1981, in Mechanical Engineering, all from Rensselaer Polytechnic Institute.

Since 1986 he has been an Associate Professor at Rensselaer Polytechnic Institute, Troy, New York. He was an Assistant Professor at Rensselaer Polytechnic Institute from 1981 to 1986. He has conducted research in the areas of robotics, computer graphics simulation, robotic autoloading, and robotic die finishing. He created the GRASP robotic simulation program, and has taught courses in the areas of robotics, mechanisms, kinematic synthesis and computer graphics.

He has been consulting for Black and Decker, American Robot Corporation, General Electric Corporate Research and Development, Benet Weapons Laboratory of the Watervliet Arsenal and Automated Dynamics Corporation in the fields of robotic simulation, robotic design, workcell design and robot kinematics.

Alan A. Desrochers attended the University of Lowell in Lowell, Massachusetts, where he received a B.S.E.E. degree in 1972. He received his M.S.E.E. degree and Ph.D. degree from Purdue University in 1973 and 1977, respectively.

During 1974 he was employed in the Guidance and Control Systems Department at the Lockheed Missiles and Space Company, Sunnyvale, California. From 1977 to 1980, he was an Assistant Professor in the Department of Systems and Computer Engineering at Boston University. During the 1986-87 academic year he was a visiting scientist in the

Laboratory for Information and Decision Systems at MIT. He is presently a Professor in the Electrical, Computer, and Systems Engineering Department at Rensselaer Polytechnic Institute and Associate Director of the NASA Center for Intelligent Robotic Systems for Space Exploration. He also participates in the Computer Integrated Manufacturing Research Program within the Center for Manufacturing Productivity and Technology Transfer. He is Chairman of the Education Committee of the IEEE Robotics and Automation Society and Technical Editor for Automation and Manufacturing Systems for the IEEE Transactions on Robotics and Automation. He is also a member of the Editorial Board for the International Journal on Production Planning and Control. In 1987 he was part of a six faculty member team that received the LEAD Award from the Society of Manufacturing Engineers. He is a member of Eta Kappa Nu, Sigma Xi, the New York Academy of Sciences and a Senior Member of IEEE. Dr. Desrochers' current interests include modeling and control of robotic manipulators and control of automated manufacturing systems.

Lester A. Gerhardt received his Bachelor's degree in Electrical Engineering in 1961 from the City College of New York, his M.S.E.E. from SUNY at Buffalo in 1964, and his Ph.D. in Electrical Engineering (specializing in communications) from SUNYAB in 1969.

He joined Bell Aerospace Corporation directly upon graduation in 1961 and remained with them until 1970. Areas of work included visual simulation of space flight, electronic image generation, analog and digital computer simulation, systems analysis, digital signal processing, image processing and pattern recognition. Beginning as an R&D engineer, he became Head of Signal and Information Processing at Bell in later years and then served as Assistant Director of Avionics Research.

In 1970, he received the Bell Outstanding Management Award.

Dr. Gerhardt was appointed as Associate Professor of Systems Engineering at RPI in 1970. He was promoted to Full Professor in 1974, and selected as Chairman of the newly-merged Electrical and Systems Engineering Department in 1975, a position he held until 1986.

The ECSE Department growth and development during these years was nationally recognized (in 1983/1984) in a National Academy of Science report "An Assessment of Research -- Doctorate Programs in the U.S. -- Engineering" by receiving the top rating in the most improved program category, as well as being rated in the top 10% in other categories.

In 1986 he was appointed Director of Computer Integrated Manufacturing at RPI. This is now the largest interdisciplinary research program on campus and has been cited as one of the largest university programs of its kind in the country. It has involved as many as 13 sponsoring corporations contributing multi-million dollar level research support, resident engineers, equipment, etc., and has a staff/faculty/student personnel complement of about 50. It involves research in control, communications and information processing/management, design, technology strategy and systems integration. In 1987, Computer Integrated Manufacturing at RPI won the National Lead Award for Excellence in CIM, awarded by SME/CASA.

He is an active researcher and teacher in his own right and has published extensively in the literature field. His areas of interest include pattern recognition and adaptive systems, digital voice, signal and image processing, computer integrated manufacturing, CAD and interactive graphics. He has over 150 publications/presentations.

On an Institute level, he was instrumental in initiating and establishing the Center for Interactive Graphics, and serves on several committees concerned with Institute computer facilities/performance.

In 1979 he became heavily involved in the formation of the RPI Center for Manufacturing Productivity, an industrial-sponsored Center in an academic setting, and served as its first Director (Acting) from 1979-1980.

He has been a National Delegate to NATO since 1980, currently chairing the Research Collaborative Grants Programme.

He has served the National Academy of Sciences in a variety of capacities, most recently chairing the AFSB Committee on Robotics and Artificial Intelligence 1986-1989, and now a member of the Committee on Tactical Communications.

He has served State and Federal governments including NYS Governor Carsey's Panel on Telecommunications with A. Kahn-economist, and serving on the Engineering Advisory Board of the National Science Foundation as well as Chairing the NSF ECSE Advisory Board.

He has or does serve on the Board of several publicly and privately held corporations, including, Computone, Capintec, Bitwise, Inc., Sykes Datatronics and Testamatic.

He is an IEEE Fellow among other honors and awards.

He is an active consultant to industry, the government and other universities. These consultancies have included General Electric, New York State, Harris, Bell, Teledyne, UTC, Aerospace Corp., MTI, Capintec, Sykes, NYNEX and NCRO.

Howard Kaufman received his BEE, MEE and Ph.D. from the Department of Electrical Engineering, Rensselaer Polytechnic Institute, Troy, New York in 1962, 1963 and 1965, respectively,

He joined the Computer Research Department of Cornell Aeronautical Laboratory, Buffalo, New York in 1965, where he was engaged in the development of procedures for applying digital computers to process estimation, identification and control. In 1968, he joined General Electric Research and Development Center as a System Engineer and developed computer simulations of large scale industrial processes.

Since 1969 he has been a member of the Electrical, Computer, and Systems Engineering Department of Rensselaer Polytechnic Institute, Troy, New York, where he is a Professor teaching courses in systems analysis, optimal and adaptive control theory and digital systems.

His research interests are in the areas of adaptive and digital systems. He has written many papers in these areas and has served as a consultant to General Electric Corporate Research and Development in related projects.

During the summer of 1972, he was awarded a NASA Summer Faculty Fellowship at NASA-Langley Research Center where he conducted research in the development of digital adaptive light control systems, and during the summer of 1982, he was an NSF Industrial Research Participant at General Electric Corporate Research and Development where he was involved in computer aided control systems design.

Dr. Kaufman is a senior member of the IEEE and is a member of Sigma Xi, Eta Kappa Nu and Tau Beta Pi honor societies.

Robert B. Kelley joined the faculty of Rensselaer Polytechnic Institute in 1985 as a Professor in the Electrical, Computer, and Systems Engineering Department. He was formally Technical Director of the Robotics Research Center and Professor of Electrical Engineering at the University of Rhode Island.

His teaching interests are primarily in computer engineering and his research interests include robotics and computer vision. He is an active researcher and consultant in the field of robotics, holds six patents, has published extensively and holds many appointments on national committees and boards.

He earned a BS from Newark College of Engineering (now New Jersey Institute of Technology), an MS from the University of Southern California, and a Ph.D. from the University of California at Los Angeles. He has served as a consultant to many large corporations, including Bendix, General Electric, E.I. DuPont de Neours and Co., the Goddard Space Flight Center of the National Aeronautics and Space Administration and FIAT in Italy.

He is a member of the National Academy of Science's Manufacturing Studies Board and Committee on Industry-Academe Cooperation, the Institute of Electrical and Electronic Engineers and serves on the Administrative Council of the Robotics and Automation Society, the Association of Computing Machinery, the American Association of Artificial Intelligence and Robotics International of the Society of Manufacturing Engineers. He was Program Chairman of the 1988 IEEE International Conference on Robotics and Automation.

L. Ken Lauderbaugh received his B.S. in Mechanical Engineering, Summa Cum Laude from the University of Michigan in 1981, his M.S. and Ph.D. in Mechanical Engineering from the University of Michigan in 1982 and 1985, respectively.

His professional experience includes: Research Assistant at the University of Michigan during 1979-1985; Research Engineer at Federal Mogul Corporation during the summers of 1981 and 1982; and since 1985 he has been an Assistant Professor in the Department of Mechanical Engineering, Rensselaer Polytechnic Institute, Troy, New York. He is also a member of the American Society of Mechanical Engineers and the Society of Manufacturing Engineers.

His current research deals with automation of drilling (AFT), adaptive control for noisy environments, manufacturing network load reduction using circular motion extraction and data compression on NC code, multivariable adaptive control for turning, and intelligent work station control. His future research interests are: robot safety, space automation, AI in control and automation and dynamic modeling of metal cutting.

Arthur C. Sanderson received his B.S. degree from Brown University in 1968 and his M.S. and Ph.D. degrees from Carnegie-Mellon University in 1970 and 1972, respectively.

From 1968 to 1970 he was a Research Engineer at Westinghouse Research Laboratories and worked on design and simulation of solid-state electronic devices. From 1972 to 1972 he was a Visiting Research Fellow at Delft University of Technology, Delft, The Netherlands, and conducted research in the areas of signal processing and pattern recognition.

From 1973 to 1987, Dr. Sanderson was a faculty member at Carnegie-Mellon University in the Department of Electrical and Computer Engineering. From 1980 to 1987 he was Professor of Electrical and Computer Engineering. Dr. Sanderson participated in the founding and development of the Robotics Institute at CMU, and was Associate Director of the Robotics Institute from 1980 to 1987. As Associate Director, he coordinated many of the research initiatives in the Institute.

From 1985 to 1987, Dr. Sanderson was on leave from CMU and held the position of Director of Information Sciences Research at Philips Laboratories, Briarcliff Manor, New York. As research Director, he developed new technical programs in Artificial Intelligence, Computer Architecture, Computer-Aided Design, and Robotics and Flexible Automation.

In 1987, Dr. Sanderson joined Rensselaer Polytechnic Institute as Professor and Department Head of the Electrical Computer and Systems Engineering Department.

Dr. Sanderson is the author of over 120 technical publications and proceedings. His current research interests include planning systems for robots and automation systems, sensor-based control, computer vision, and applications of knowledge-based systems.

He is a Senior Member of the IEEE and President of the IEEE Robotics and Automation Society. He is a member of AAAI, SME and AAAS.

George N. Saridis was born in Athens, Greece. He received a diploma in Mechanical and Electrical Engineering from the National Technical University of Athens, Athens Greece, in 1955 and the M.S.E.E. and Ph.D. degrees from Purdue University, West Lafayette, Indiana in 1962 and 1965, respectively.

From 1955 to 1961 he was an instructor in the Department of Mechanical and Electrical Engineering from the National Technical University of Athens. Since 1963, he has been with the School of Electrical Engineering, Purdue University. He was an instructor until 1965, an Assistant Professor until 1970, an Associate Professor until 1975, and a Professor of Electrical Engineering until 1981. Since September 1981, he has been a Professor of the Electrical, Computer, and Systems Engineering Department and Director of the Robotics and Automation Laboratories at Rensselaer Polytechnic Institute. In 1973 he served as a Program Director of System Theory and Applications at the Engineering Division of the National Science Foundation.

Dr. Saridis is a Fellow of IEEE and a member of a Sigma Xi, Tau Beta Pi, Eta Kappa Nu, the Academy of Sciences of New York, the American Society of Mechanical Engineers, Robotics International of the Society of Manufacturing Engineers, American Association of University Professors and American Society of Engineering Education. In 1972-73 he was the Associate Editor and Chairman of the Technical Committee on Adaptive Learning Systems and Pattern Recognition of the Society of Control Systems of the IEEE, Chairman of the 11th Symposium of Adaptive Processes, IEEE delegate to 1973 and 1976 JACC, and Program Chairman of the 1977 JACC. In 1973 and 1979 he was elected as a member of the ADCOM of the Society of Control Systems of the IEEE. From 1979-81 he was appointed Chairman of the Education Committee of the above society. He was the International Program Committee Chairman of the 1982 IFAC Symposium on Robotics. In 1975 and 1981 he was appointed Vice Chairman of the IFAC International committee on Education and from 1981-84 he was the Survey Paper Editor for *Automatica*, the IFAC Journal and Editor of the JAI Publications *Annual Advances in Robotics and Automation*. In 1986 he was appointed chairman of the Control Systems Society's Committee on Intelligent Controls and chairman of the Awards Committee of the Robotics and Automation Council. Dr. Saridis is also the author of the book, *Self-Organizing Control of Stochastic Systems*, editor of the book *Annual Advances in Automation and Robotics, Vol. 1*, and co-editor of the book *Fuzzy and Decision Processes*. He has also written over 200 book chapters, journal articles, conference papers and technical reports.

Chi-Neng Shen is a Professor Emeritus with the Electrical, Computer, and Systems Engineering Department at Rensselaer Polytechnic Institute. He received his Ph.D. from the University of Minnesota in 1954. He has the following years of academic service: 1 year at Massachusetts Institute of Technology; 4 years at Thayer School of Engineers, Dartmouth College;

and 28 years at Rensselaer Polytechnic Institute. He belongs to the following scientific and technical societies: IEEE, ASME, ANS and Sigma Xi.

He has received research support and funding for 20 years from NASA, 4 years from the Department of Defense and 3 years from the U.S. Nuclear Regulatory Commission. He served for 20 years as consultant in Applied Mathematics and Mechanics Section, Benet Weapons Laboratory, U.S. Army.

Dr. Shen has 40 publications in reviewed journals and conference proceedings since 1980.

John Wen received his B.Eng. degree from McGill University in 1979, his M.S. degree from the University of Illinois at Champaign-Urbana in 1981, and Ph.D. degree at Rensselaer Polytechnic Institute in 1985, all in Electrical Engineering.

From 1981-1982 he was a Systems Engineer at Fisher Controls Inc. in Marshalltown, IA, where he worked on the production rate control for a pulp and paper plant. From 1985 to 1988, he was a member of the technical staff at the Jet Propulsion Laboratory where he did research in the areas of the control of flexible space structures and the control of multiple robot manipulators. He joined the faculty of the Department of Electrical, Computer, and Systems Engineering at Rensselaer Polytechnic Institute in August 1988, where he is currently an Assistant Professor. Dr. Wen is a member of IEEE, SIAM, Tau Beta Pi and Sigma Xi.

His current research interests include: control of distributed parameter systems, control of interconnected mechanical systems such as robots and adaptive control.

CIRSSE REPORTS

CIRSSE REPORTS

- CIRSSE 1:** "Analytic Formulation of Intelligent Machines as Neural Nets", by G.N. Saridis and M.C. Moed; October 1988.
- CIRSSE 2:** "Intelligent Machines: Distributed versus Hierarchical Intelligence", by G.N. Saridis; October 1988.
- CIRSSE 3:** "An Analytic Formulation of Knowledge-Based Systems for Intelligent Machines", by G.N. Saridis; October 1988.
- CIRSSE 4:** "Acceleration and Torque Feedback for Robotic Control: Experimental and Theoretical Results", by J.E. McInroy and G.N. Saridis; November 1988.
- CIRSSE 5:** "Analytic Formulation of the Principle of Increasing Precision with Decreasing Intelligence for Intelligent Machines", by G.N. Saridis; October 1988.
- CIRSSE 6:** "Analytical Design of Intelligent Machines", by G.N. Saridis and K.P. Valavanis; October 1988.
- CIRSSE 7:** "Knowledge-Based Robot Workstation", by R.B. Kelley; October 1988.
- CIRSSE 8:** "2D Vision Techniques for the Handling of Limp Materials", by R.B. Kelley; October 1988.
- CIRSSE 9:** "A Representation Scheme for Rapid 3-D Collision Detection", by R.B. Kelley and S. Bonner; August 1988.
- CIRSSE 10:** "Issues in the Safety of Complex Systems", by V.J. Ree, Jr. and L.K. Lauderbaugh; November 1988.
- CIRSSE 11:** "Minimum-Time Control of Robotic Manipulators", by Y. Chen; August 1988.
- CIRSSE 12:** "Obstacle Avoidance Path Planning by the Extended VGraph Algorithm", by C.H. Chung and G.N. Saridis; January 1989.
- CIRSSE 13:** "Robustness Analysis for Evolution Systems in Hilbert Space: A Passivity Approach", by J.T.-Y. Wen; December 1988.
- CIRSSE 14:** "A Matrix Safety Frame Approach to Robot Safety for Space Applications", by T.D. Montgomery; December 1988.

- CIRSSE 15:** "Coordination Model for Intelligent Machines", by F.Y. Wang and G.N. Saridis; January 1989.
- CIRSSE 16:** "Planning 3-D Collision-Free Paths Using Spheres", by S. Bonner and R.B. Kelley; January 1989.
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